(12) EUROPEAN PATENT APPLICATION

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(54) Digital bi - static spread spectrum radar

(57) Bi-static radar, with pseudo-random signal transmission, constituted by a transmitter and a receiver connected to separate antennas placed at distant locations. Pseudo-random (spread spectrum) signal transmission allows to detect less reflective and more distant targets when compared to traditional radar with the same available power and bandwidth. This result (as all range cells of all receiving beams are simultaneously processed in parallel) is due to the greater energy incident on the target and the peculiar receiver . The receiver beams simultaneity is due to joint use of receiving array antenna and digital beam-forming techniques. The parallel analysis of all range cells is assured by the architecture of the digital receiver. The radar exhibits low probability of detection by ECM receivers and excellent anti-jamming resistance. The radar can be used in military, civil and scientific appications and in the guidance of devices using passive sensors.
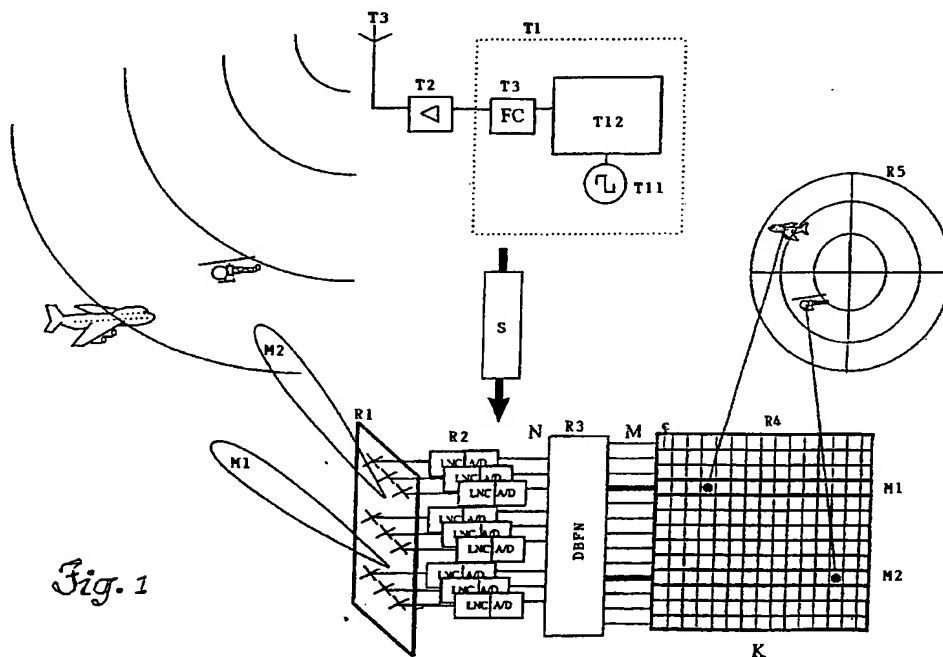
Fig. 1

EP 0 893 703 A1

sults very difficult to detect and/or less disturbing towards other systems (low interference). This means that the radar exhibits LPI/LI (Low Probability of Intercept/Low Interference) properties.

- The transmitting antenna appears, from the transmitted signal (signature) point of view, as a generic telecommunication transmitter and allows for a better camouflage of the radar itself.

- The availability of many classes of spread spectrum signals allows for a code agility, that, joined with the usual frequency agility, makes very difficult the ECM (Electronic Counter Measures) techniques.

- The anti-ECM resistance characteristics are enhanced with respect to the intentional disturbances (jamming), that are reduced both by the processing gain associated with the spread spectrum signal usage, and by the possibility to reduce the receiving array antenna gain in the direction of the noise source (jammer), with the use of the "nulling lobe" classic technique, in the digital beam forming network.

- By the absence of refrigerating devices and antenna rotation devices, the antenna assembly is simplified (with a further reduction of weight), and this ensures to the radar a better reliability and capability to withstand the environmental stress, either natural or intentional.

In summary, the present radar has a very low probability to be detected (LPI Low Probability of Intercept), exhibits a good resistance to jamming (AJ Anti-Jamming), shows a low ARM (Anti Radiation Missiles) missiles vulnerability due to the array passive receiving antenna and, particularly, it has better detection characteristics, with equality of available transmitted power.

The invention is located in the scientific field of radar, more particularly in the military radar field, with surveillance finality and eventually as an help to the guidance of devices using passive sensors, and it is applicable both in the military, and in the civil application field.

The radar to which present patent request refers, is constituted of a transmitter and a receiver respectively connected to physically separated antennas, also of different type, that can be installed in different locations, also very far away from each other.

The transmitting antenna can be of various types: dipole, Yagi, reflector antenna, horn radiator antenna, array antenna, etc., depending on the radar working frequency and the desired polarization, provided that it can show coverage characteristics matching the surveillance volume. For example, if an essentially omnidirectional azimuth coverage, with an elevation angle not too high, is requested, a simple vertical dipole can be used.

The transmitter must continuously radiate in the surveillanc volume, a pseudo-random signal (pseudo noise), centered on the requested carrier radio frequency, with a power adequate to the requested range of the target type of interest.

As well known, a pseudo - random signal, often indicated as "pseudo noise" or "spread spectrum", shows the characteristic to have autocorrelation properties, very similar to the noise, but to be nevertheless of deterministic type, that is well known a priori to the radar receiver. A "pseudo noise" type signal, which can be used, is the signal described in the literature as "direct sequence spread spectrum" (DS - SS), that is made of a sequence of digital pulses produced by a "pseudo noise" code generator.

It is useful to note that also other pseudo-random signal types ("pseudo noise" or "spread spectrum"), with autocorrelation characteristics similar to that of the noise, could be used with an equal profit by the system.

The pseudo - random signal is converted to the interested transmission frequency, with a simple or multiple frequency conversion technique. In the event that it is interesting to periodically change the carrier radio frequency, it is possible to employ the frequency agility technique, described in the literature as "frequency hopping" (FH).

An essential advantageous characteristic of the radar transmitter is the possibility to generate, with direct digital synthesis techniques, the "spread spectrum" signal in base band (BB), and to convert it, in a second time, to the final transmission frequency, or the one to generate directly its version centered on the intermediate frequency (IF), or finally to generate its version centered directly on the carrier transmission frequency. If it is chosen the direct digital synthesis of the pseudo-random signal (spread spectrum) directly into the intermediate frequency (IF), or into the final radio frequency, the total number of the frequency conversions needed is lower.

The receiving antenna is constituted by an array of elementary receiving antennas. The elementary antennas can also be of different types, for example dipole, horn radiator, Yagi, microstrip, etc.

Each elementary antenna of the receiving array is directly connected to a frequency converter with a low noise figure (low noise figure (block) frequency (down) converter), that, in turn, feeds an analog-to-digital dedicated converter (A/D converter). The A/D conversion frequency is sufficiently high to allow both the correct conversion of the received signal, and to avoid the phenomenon known as "aliasing". The number of bit of the A/D converter is such as to ensure the correct operation of the radar in the whole expected dynamic of the received signal.

The digital streams coming from each element of the array (with "element" we intend the set of elementary antenna, the "low noise" frequency converter and the A/D converter) feed the digital beam former ("digital beam forming network"). This has as many (digital) inputs as the number of elements of the array and as many (digital) outputs as the number of beams necessary to cover the space sector of interest.

For example, if we needed 250 beams and the array

range cells of interest. In the schematic diagram it can be noted that the presence of targets in the beams M1 and M2 produces a correlation peak in correspondence of the range cells marked with a little black dot (•).

R5 indicates the digital presentation device of the processed radar signal, or another system to which the digital information provided by the radar is to be sent. In the schematic diagram we have indicated, to be simple, a display device of PPI type.

S indicates the auxiliary synchronization channel. This channel carries the information relative to the frequency currently in use, to make a correct low noise figure frequency conversion of R2, and also the information relative to the initial time of generation of the transmitted base pseudo random signal and in the case the digital clock (optional).

With reference to Fig. 2, it is showed the detecting principle (with correlation) of the received pseudo random signal, containing the information of the target presence.

In Fig. 2-f), the Es echo signal, coming from a generic beam, is received by the array antenna R1, processed as described in Fig. 1, until the output of the signal from the digital beam forming network. The digital signal received is then correlated with copies of the reference signal SF, suitably delayed on the base of range cell that will be observed. When the echo signal eventually received is aligned with the delayed copy of the reference signal SF, corresponding to the range cell observed, the correlation peak detecting the target is obtained.

The two processors described are used for the same finality of target detection, with the difference that the first described (Fig. 6) allows the detection of the target at the end of signal reception, while the second (Fig. 7) allows the partial detection of the target during the reception of the pseudo random sequence. These processors represent one of the interesting aspects of the present patent pending.

With reference to Fig. 2 e), it is showed there the echo of return signal after the digital beam forming network and the replicas SF of the reference signal which are time delayed of a quantity corresponding to the c cell distance.

With reference to the Figs. 3 and 4, it is showed the comparison between the performance of a pulsed radar and that of the bi-static spread spectrum digital radar, in terms of signal to noise ratio, and therefore of target "detecting capability". It can be noted the advantage, in the specific case, of about 40 dB, due to the "processing gain", or, more simply, to the integration of the greater energy incident on the target. As already said, the correlation digital receiver can be implemented in two different configurations, showed in Fig. 6 and Fig. 7.

In the case of Fig. 6, the correlation digital receivers (R4) operate on a digital correlation simplified architecture basis, which can be better realized with a processor of DSP (Digital signal Processor) type, to which are assigned the functions of sub-correlation of the received

signal (I and Q components) with time-delayed replicas of the time τ of the transmitted signal, their partial integration Σ and its successive processing by the FFT These DSP are commercially available. It must be noted that the sub correlation and the successive processing by the FFT allow on one hand to avoid the "destructive" phase lag on the correlation gain introduced by the Doppler effect associated to the radial velocity of the target obtaining on the other hand as an additive result the detecting and the estimate of the Doppler itself.

In the case of Fig. 7, the correlation digital receivers (R4) are realized using one or more dedicated devices (ASIC, FPGA, etc.), made of process elements composed by two registers for the I and Q components of the received signal (Reg. I and Reg. Q), by the elementary correlators of the reference signal (a1. a2   aN) by the partial adders Σ, by the FFT with N inputs and N outputs, by the module extractor (MODEXTR) with N inputs and N outputs, by the maximum detector (MAX) and by a further sawtooth correlator.

Claims

1. Bi-static spread spectrum digital radar. characterized by the fact to be constituted (Fig. 1) by a pseudo random digital signal generator (T12). by the digital clock generator (T11), by the frequency converter (FC-T13), by the power amplifier (T2) by the transmitting antenna (T3), by the receiving array antenna (R1), by the set of low noise figure frequency converters (R2 LNC) and by the set of analog to digital converters (R2 A/D), by the digital beam forming network (R3) and by the set of correlation digital receivers associated with the resolution cells (R4) integrated into one or more dedicated or not dedicated processors, by a detected signal presentation device or by a system to which the radar digital information can be sent (R5).

2. Bi-static spread spectrum digital radar, according to claim 1, characterized by the fact that the pseudo random signal generator (T12) is a digital generator of variable length pseudo random codes, pertaining to the code classes with minimum correlation. and is a commercially available device.

3. Bi-static spread spectrum digital radar, according to claim 1, characterized by the fact that the so called digital clock generator (T11) is an high stability device, with a quartz or rubidium or cesium or GPS (Global Position System) signal derived frequency reference; this device is commercially available.

4. Bi-static spread spectrum digital radar, according to claim 1, characterized by the fact that the so called frequency converter (FC-T13), is constituted by oscillators, filters and mixers, and is commercially
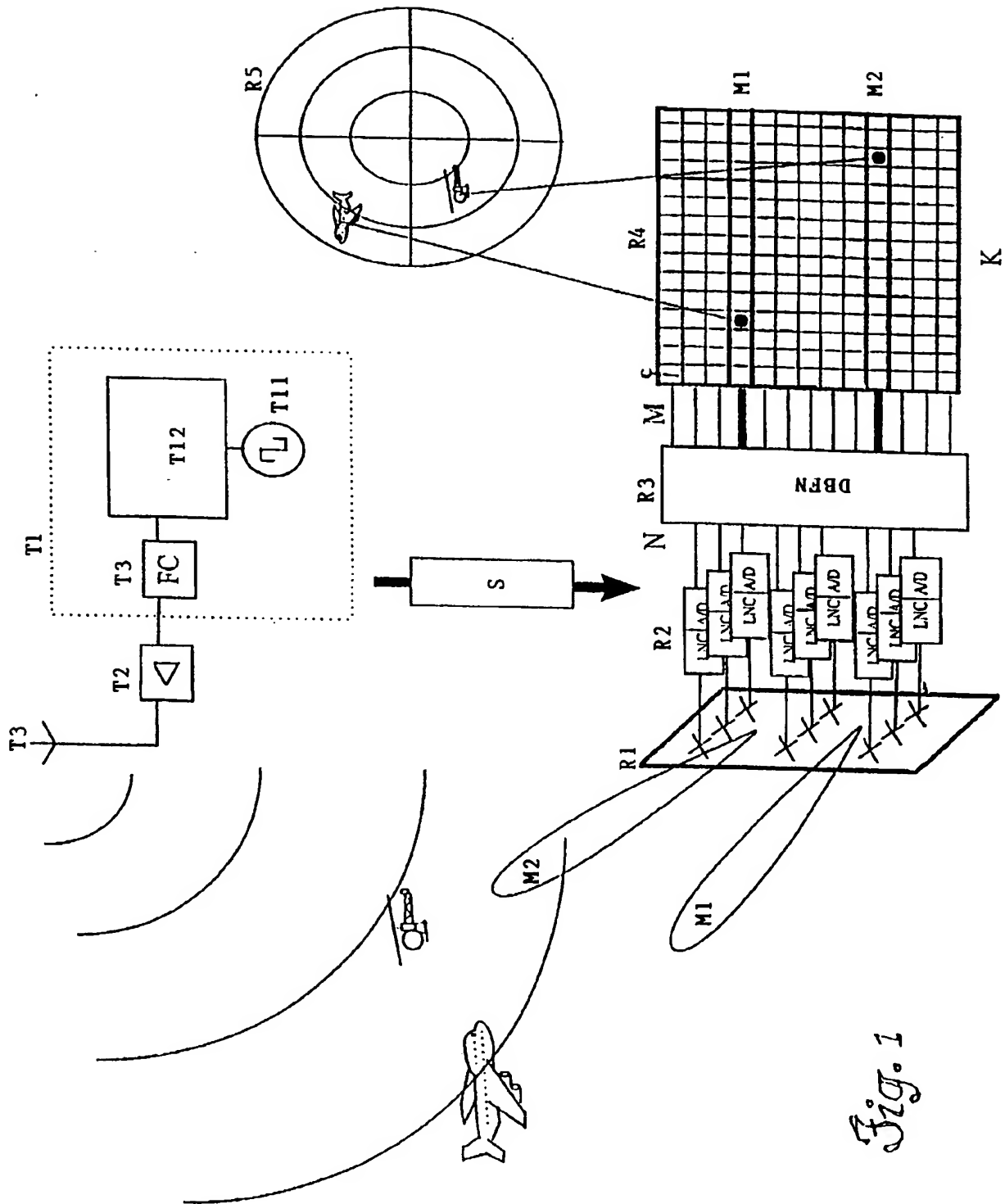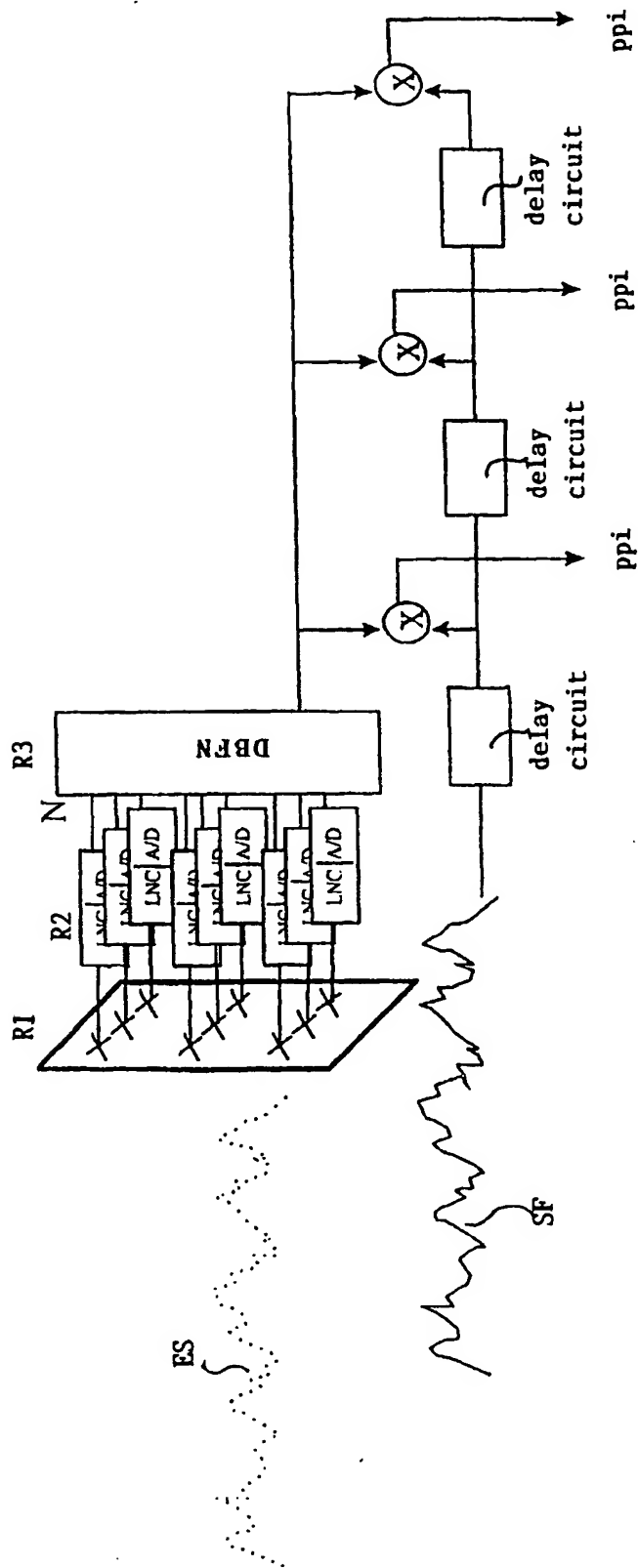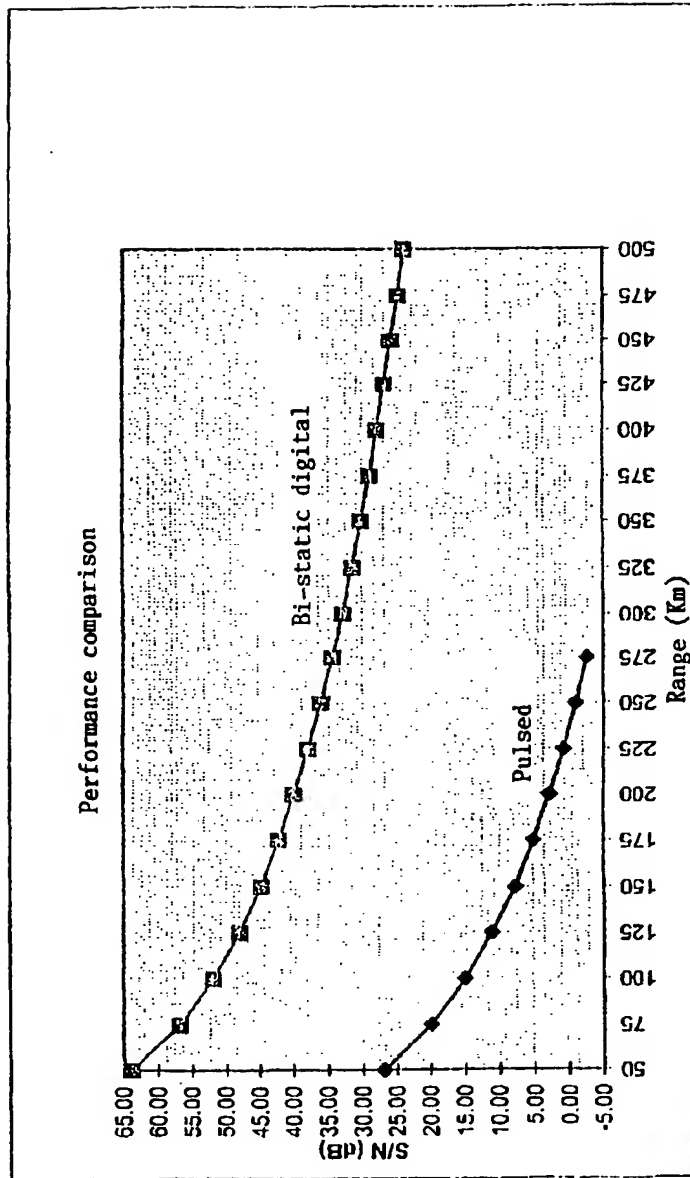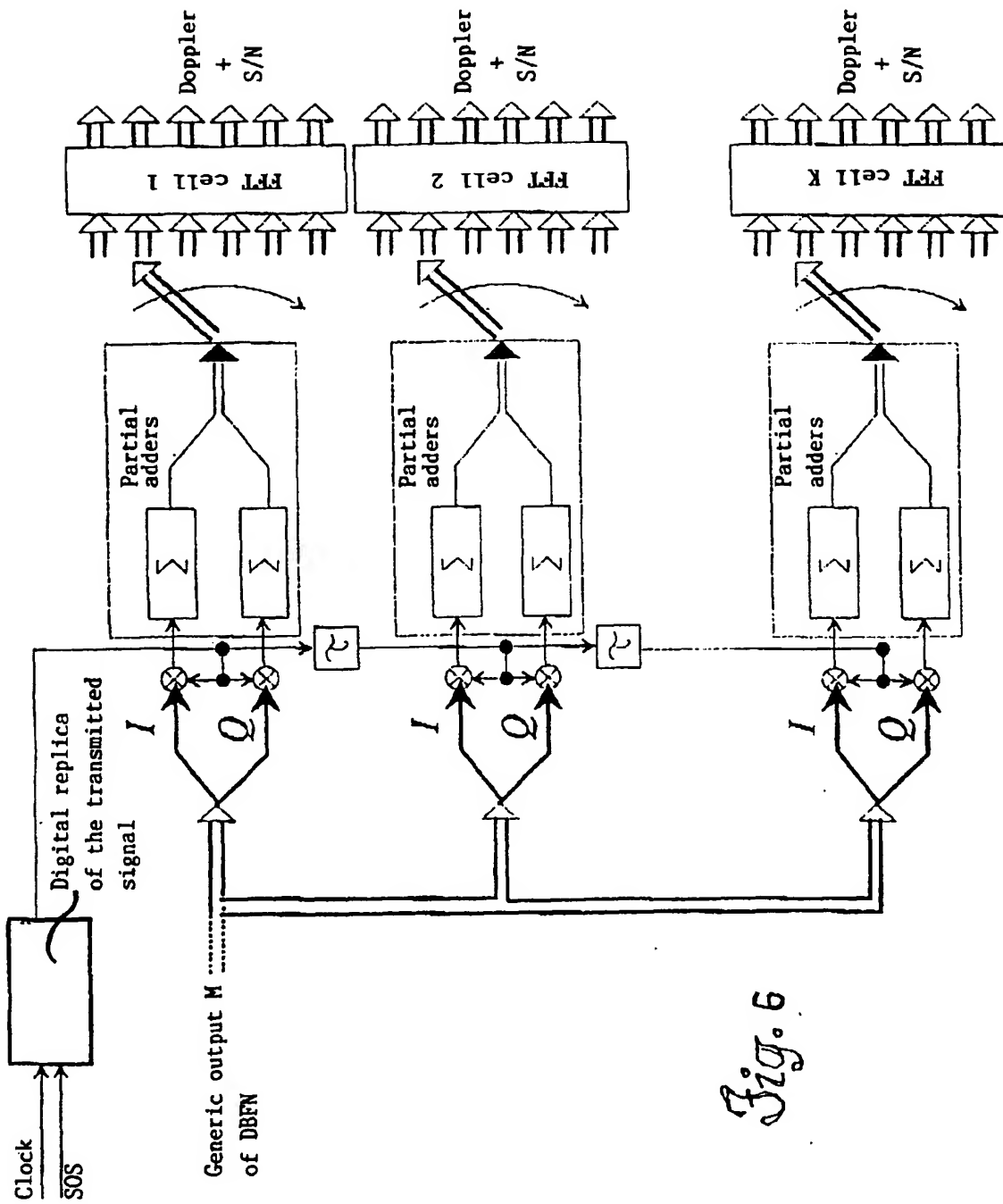
Fig. 1

Fig. 2 f)

Fig. 4

Fig. 6

| | European Patent Office | EUROPEAN SEARCH REPORT | | Application Number EP 98 83 0378 |

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Y	BETTS: "An X-Band Bistatic Radar System" EUROPEAN MICROWAVE CONFERENCE, vol. 1, - 13 September 1990 pages 867-873, XP000327018 BUDAPEST HUNGARY * page 861 - page 872 *	1,10	G01S13/00
Y	BLATTMAN: "Spread Spectrum Technology Applied to Microwave Bistatic Intrusion Detection sensors" PROCEEDINGS 1985 CARNAHAN CONFERENCE ON SECURITY TECHNOLOGY, - 17 May 1985 pages 65-74, XP002079465 Univ of Kentucky, Lexington , Kentucky USA	1,10	
A	* page 67 - page 70 * * page 73 *	11,12	
A	EP 0 681 190 A (THOMSON CSF) 8 November 1995 * abstract; claims; figures *	1,10-12	
A	US 5 265 121 A (STEWART CLARENCE H) 23 November 1993 * abstract; claims; figures *	1,10-12	TECHNICAL FIELDS SEARCHED (Int.Cl.6) G01S
A	US 4 605 922 A (BLATTMAN DANIEL A ET AL) 12 August 1986 * abstract; claims; figures *	1	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	2 October 1998	Devine, J

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